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GB 2202046 A GB 2190262 A GB 2126820 A

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(54) An optical fibre sensor array

(57) A linear strain sensor is described, consisting of a cabled or jacketed optical fibre. Light travelling through the fibre, is phase modulated by the strain, which is detected using reflectometric interferometry. The sensor is suitable for intruder detection, structural monitoring and monitoring of vehicles on the highways.

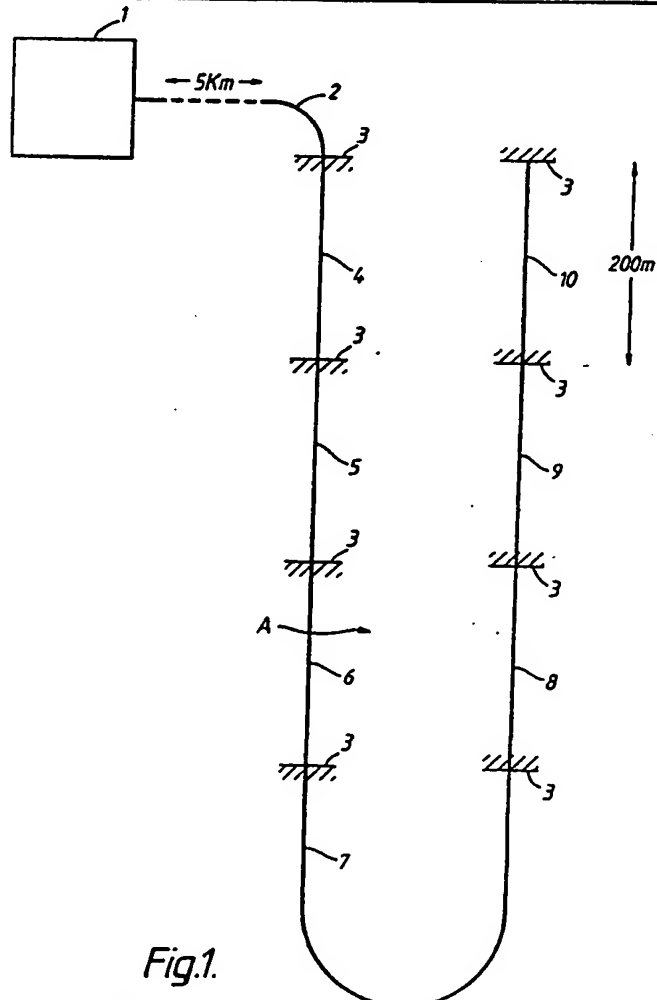


Fig.1.

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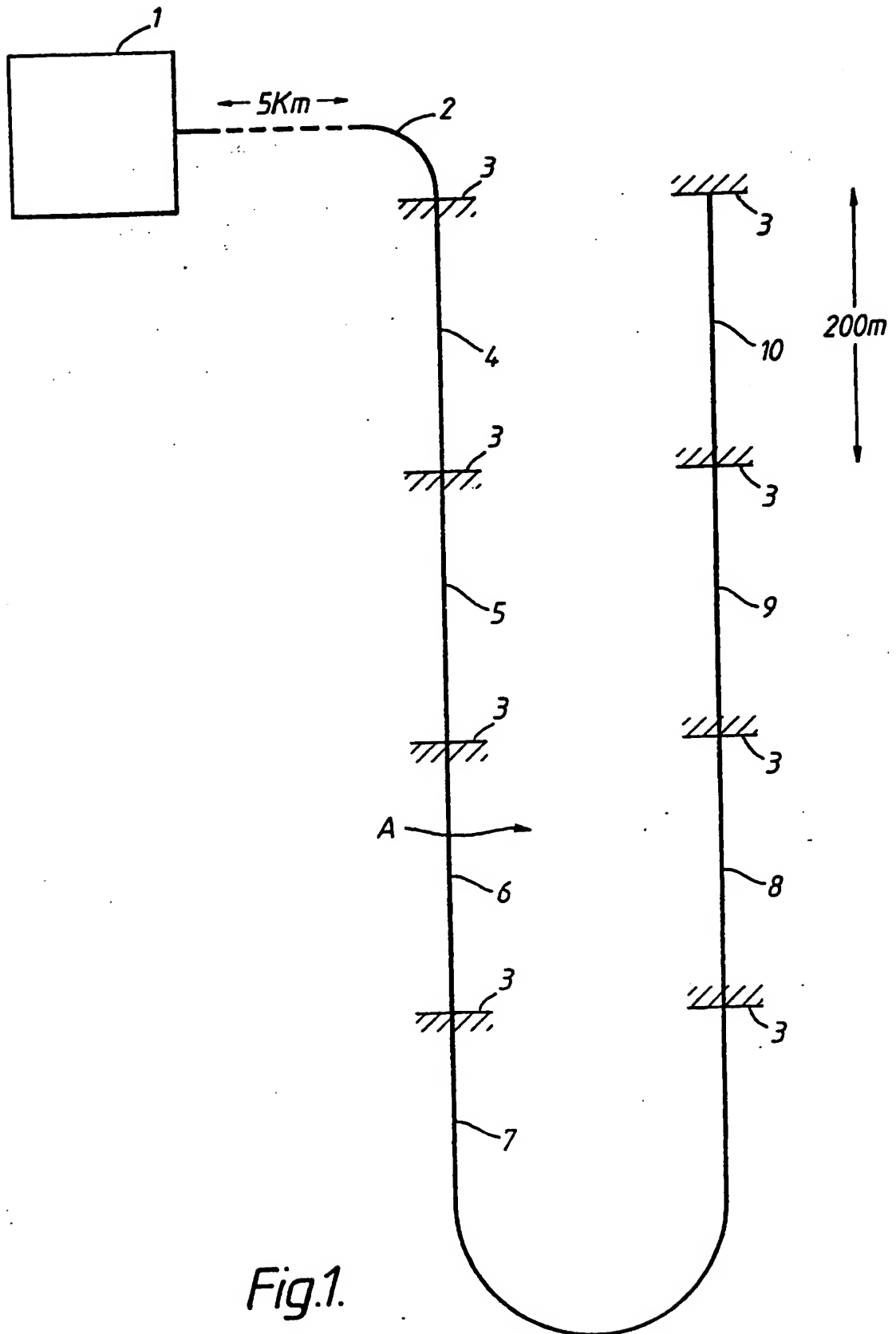


Fig.1.

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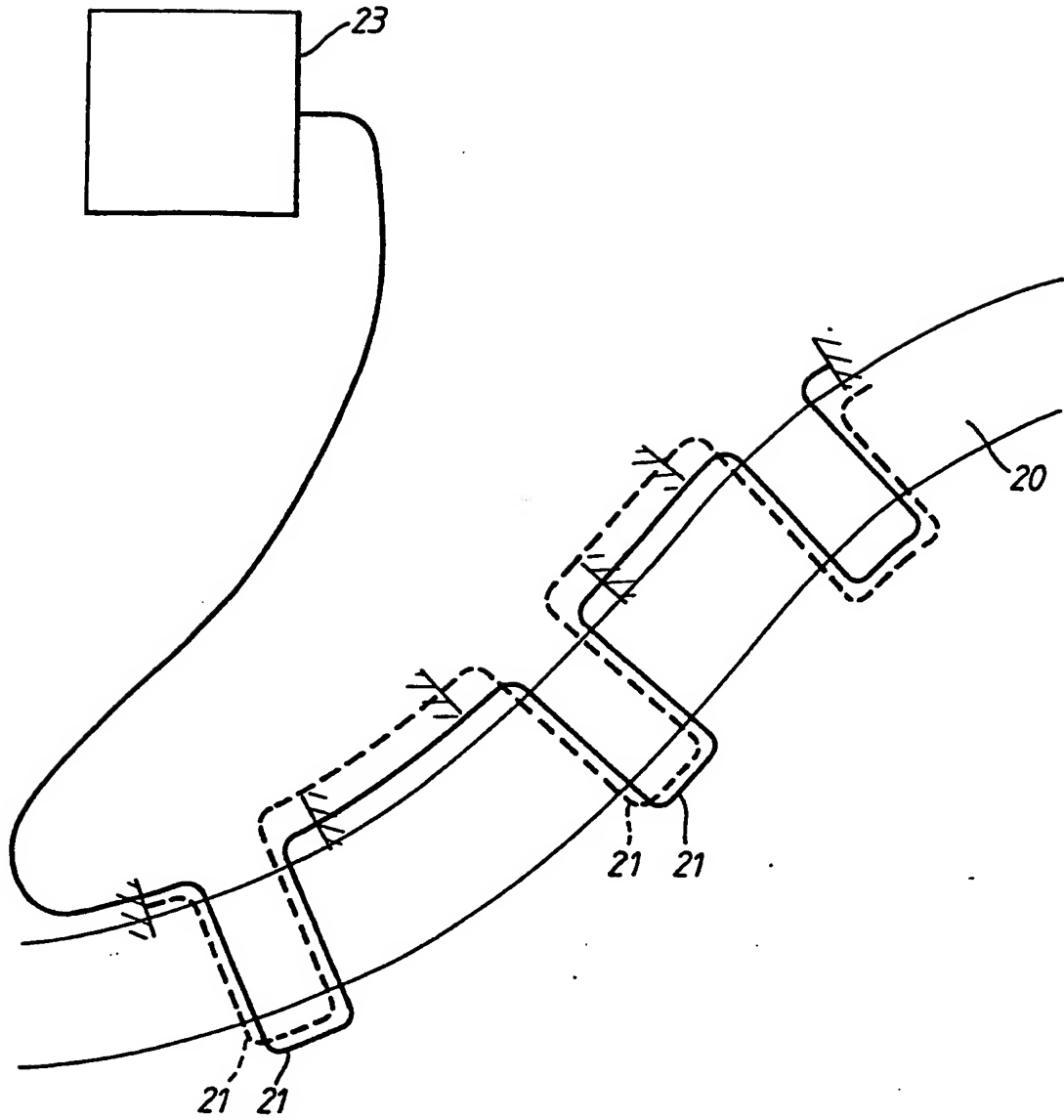


Fig.2.

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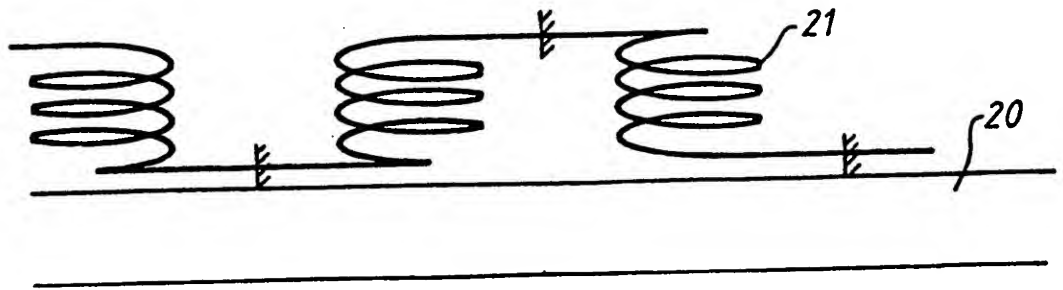


Fig. 3.

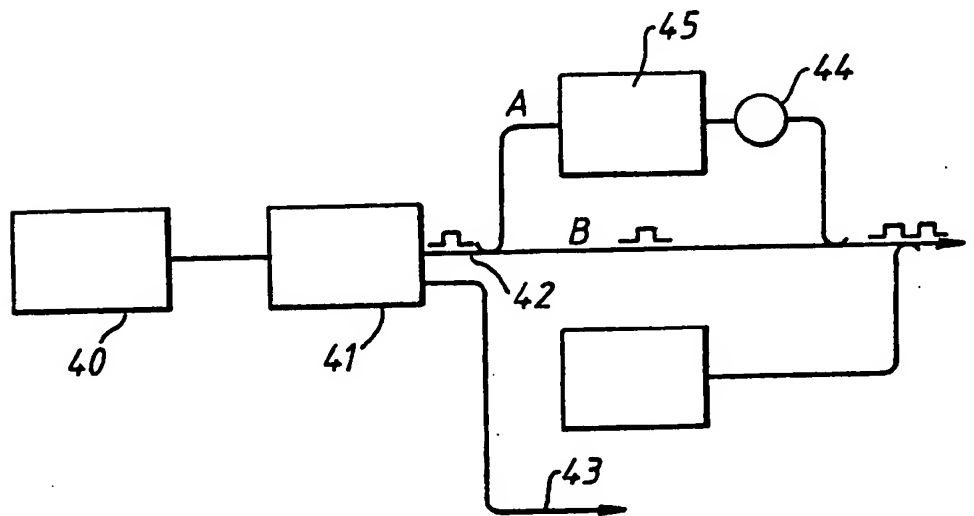


Fig. 4.

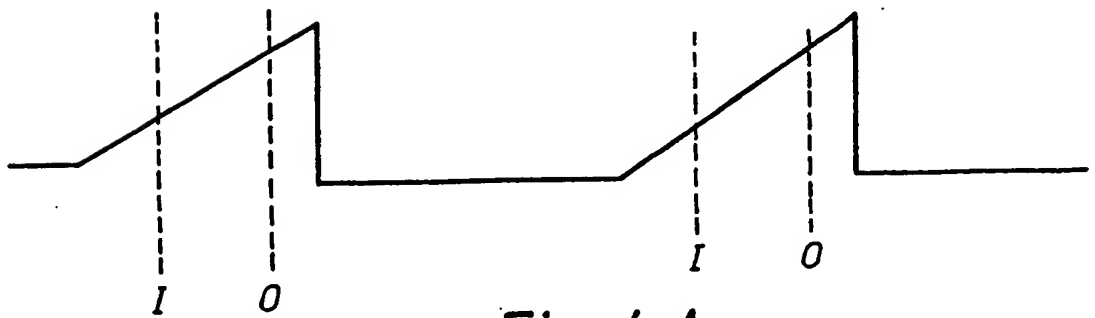


Fig. 4 A.

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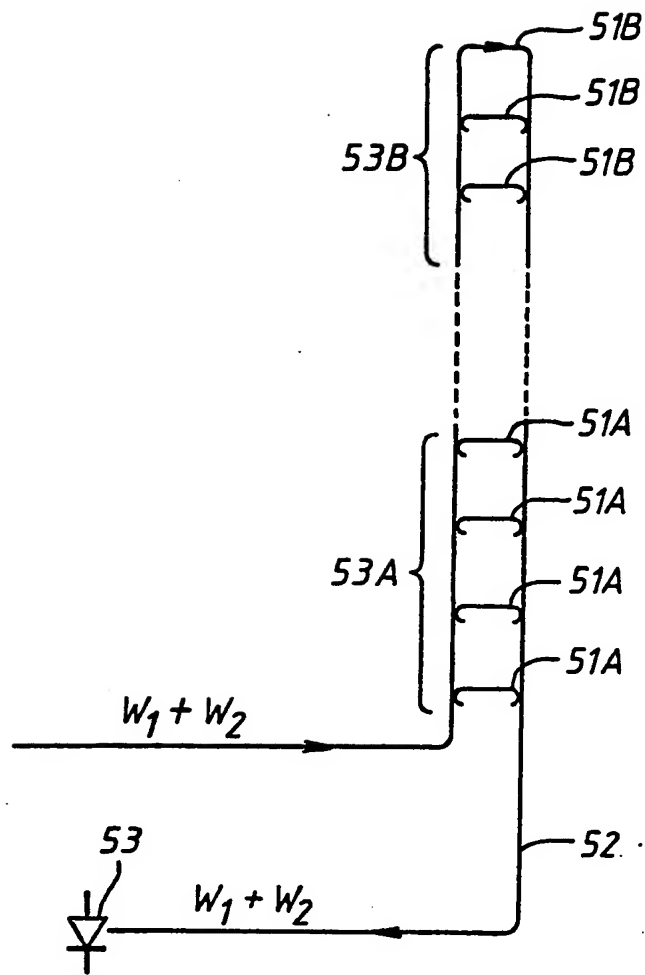


Fig. 5.

An Optical Fibre Sensor Array

This invention relates to an optical fibre sensor array, and in particular to such an array for detecting strain.

Optical fibres have been employed in many types of detection systems. One particular application in which they have previously been used is for the detection of acoustic pressure waves in water. In order to detect such pressure waves and to obtain information about the wave, for example directivity, it is necessary to employ a plurality of optical fibre sensors usually in a linear array. As such arrays are often towed behind a marine vessel optical sensors arrays for such applications have been developed so that the sensor array comprises of only optical fibre material, all contact with the array being by the propagation of light along the fibre, enabling all the electronics for producing the light signals and processing the received signals to be mounted remote from the array for example on board the marine vessel towing the array.

One such optical sensing system as described above is disclosed in our UK patent application Publication No.

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2136113. This discloses a sensor array comprising a single optical fibre 6, having along its length discontinuities which define respective sensors comprising of the lengths of fibre between each adjacent pair of discontinuities. A similar arrangement is shown in our co-pending application number 9124589.4 wherein a plurality of light sources are used to send a plurality of light signals down a single fibre, with respective sets of optical sensing elements being associated with different light sources enabling a greater number of optical sensors to be deployed.

The present invention arose from the realisation that apparatus similar to that disclosed in the above referred to applications could be advantageously applied for detecting strain on the surface of, or within, a structure.

According to the present invention there is provided an optical fibre sensor array including an optical fibre, a light source for transmitting light signals into the fibre, and detector means, the fibre comprising a plurality of sensor elements, each being a length of the optical fibre positioned on, or under, a surface on which strain is to be detected, the lengths of optical fibre being defined by redirecting means for redirecting light signals propagated along the sensor array to the detecting means.

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By providing an optical fibre sensor in accordance with the invention it is possible to sense strain at multiple locations, with the only connection required being by a single optical fibre. This provides that the electronic processing data and light source can be far removed from the sensed area and does not require electrical signals to be transmitted to the sensed area, which may be advantageous in areas of high fire risk.

Preferably the redirecting means comprises partial reflectors for reflecting light signals back along the single optical fibre to the detector arrangement such that only one fibre need be provided between the light source/detector arrangement and the sensor elements. These partial reflectors may be reflective optical couplers. Alternatively the redirecting means may comprise optical coupling means for redirecting light to an optical fibre other than said single optical fibre for transmission to the optical detector arrangement.

Advantageously a reference cable is positioned in close proximity to the sensor array to permit common-mode noise to be cancelled, for example laser noise or geological noise, which would be common-mode rejected, leading to a



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lowering of the noise floor and hence an increase in sensitivity.

In certain applications it is desirable that the detection means comprises means for analysing the return signal and means for comparing it with stored data in order to classify the detection and thereby identify what has been detected.

Preferably the light source comprises a laser source and an optical switch for directing light from the laser source along two paths one of which has an optical delay therein and one of which has an optical phase shifter therein, such that in use the light source transmits to the fibre two time displaced pulses at different frequencies, such an arrangement permitting a semiconductor laser to be used as the light source.

An array in accordance with the invention can advantageously be employed for monitoring vehicles on a highway, for detecting an intruder, or for detecting displacement of machinery. Several embodiments of the invention will now be described by way of example only with reference to the accompanying drawings of which:

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Figure 1 is a schematic illustration of an intruder detection system in accordance with the invention;

Figure 2 is a schematic diagram of a vehicle monitoring system in accordance with the invention;

Figure 3 is a schematic diagram of an alternative arrangement of the apparatus of Figure 2;

Figure 4 schematically illustrates a light source arrangement;

Figure 4a schematically illustrates the output of the light source of Figure 4; and

Figure 5 depicts one possible sensor arrangement in accordance with the invention.

The devices depicted in the Figures use the modulation of rays of light within the fibre caused by straining of the fibre.

Referring now to Figure 1 there is illustrated an intruder detection system comprising a control point 1 housing a light source and detector arrangement, a fibre

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optic cable 2 surrounded by a Kevlar\* strain member and overlaid with a protective plastic jacket. Attached to the optical fibre 2 are optical couplers 3 forming reflective discontinuities which redirect part of the light signal propagating along the fibre from the light source in the control point 1 back to the detector in the control point. Each section of fibre 4,5,6,7,8,9 and 10 between each pair of adjacent optical couplers 3 forms a sensor element. These sensor elements are placed just below ground level so that they are strained by an intruder placing his weight on the ground in the region of these elements.

An intruder crossing the double line of buried sensors at 'A' will be detected by sensor 6, followed by sensor 8, providing speed and direction information. Sensors 6 and 8 are arranged so that their outputs are set to cancel each other in the electronic processing within the detector. In this case, any common mode ambient or instrumental variations due, for example, to laser noise or geological noise, will be common mode rejected, leading to a lowering of the noise floor and hence an increase in sensitivity.

\* A TRADE MARK

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In the example shown in Figure 1, a total invigilated length of 600 metres is shown, situated at a distance of 5Km from the control point 1. This can be greater both in detection length and in downlink length, with intruder localisation to within 100-200 metres.

Signal demodulation is carried out in control point 1 by methods currently used in optical hydrophone arrangements. Typical signatures, (footsteps for example), occupy a restricted frequency range (below 500Hz) and have a characteristic spectrum. Knowledge of this spectrum provides a method of classification, following detection (using for example a simple level detector). Matched filtering, and correlation techniques are used, with stored replica target characteristics.

Referring to Figure 2, another application is illustrated for monitoring vehicles on a highway 20. Fibres 21, similar to these described with reference to Figure 1, are laid under the highway 20 and monitor the axle weight and speed of vehicles crossing the cable, the amplitude of the signal being related to the force (and hence vehicle weight) impressed on the cable. The signals are generated at control point 23 which also processes the returned signals. A second set of reference cables could be placed

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close to the first set, to cancel the effects of common-mode noise from sources other than traffic.

An alternative approach which reduces installation costs on existing carrageways is illustrated in Figure 3. Here the cables 31 are located at the side of the road (or in the central reservation). This is more difficult to calibrate and is less sensitive than the Figure 2 arrangement, but appropriate configuration of the cable run (either as, a column or zigzag) either in the surface of the roadside, or off the road, can allow satisfactory operation in certain applications.

A further application of the strain sensor (not illustrated) is for monitoring vibration of machinery, structures, aircraft etc. In these cases the cable is incorporated within the structure or attached to the outside. Vibration above 1-5Hz can be monitored, and any change in characteristics of the spectrum or amplitude detected. The advantage of this technique is the economical deployment of many sensors, so in this case, it would be of most advantage in very large structures such as ships, oil rigs etc.

Figure 4 depicts apparatus suitable as a light source

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for the systems described with reference to Figures 1 to 4. This comprises a semiconductor laser 40 which generates light that passes through a switch 41 producing a pulse on fibre 41. The switch can be connected to produce pulses on similar lines 43 (only one of which is shown) leading to similar arrays. The pulse traveling along fibre 42 travels on two paths A and B. A fibre delay 44 in path A causes a pulse entering the system to leave as two separated pulses, as required for the multiplexing scheme. Also in path A there is an optical phase shifter 45 capable of providing a linear phase ramp on one of the pulses. This results in an effective optical frequency change on one of the pulses, as required. Timing of this scheme is shown in Figure 4a, in which a linear phase ramp is shown. Alternatively a phase sinusoid could be used, and switched only on the linear portion. The required phase ramp (or sinusoid) could be obtained in two ways, either by winding fibre on a piezoelectric "stretcher" mandrel, or by using an integrated optical phase shifter. The delay 44 can be a fibre coil.

Referring now to Figure 5, there is illustrated a variation on the apparatus previously described, wherein the optical couplers 51A and 51B are frequency dependant, 51A being transmissive to a first frequency  $W_1$ , and 51B being transmissive to a second frequency  $W_2$ . In this way sensor

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elements 53A and 53B only modify W1 or W2 respectively enabling extended arrays of sensors to be provided, as for example in this embodiment signals of wavelength W2 will not be attenuated by couplers 51A. These couplers can be reflective, as previously described, or alternatively as disclosed in Figure 5, couple signals to a return fibre 52.

Claims

1. An optical fibre sensor array including an optical fibre, a light source for transmitting light signals into the fibre, and detector means, the fibre comprising a plurality of sensor elements, each consisting of a length of the optical fibre positioned on, or under, a surface on which strain is to be detected, the lengths of optical fibre being defined by redirecting means, the redirecting means redirecting light signals propagated along the sensor array to the detecting means.

2. A sensor array as claimed in any preceding claim wherein the redirecting means comprise partial reflectors for reflecting light signals back along the single optical fibre to the detector arrangement.

3. A sensor array as claimed in claim 2 wherein said reflectors comprise reflective optical couplers.

4. A sensor array as claimed in claim 1 wherein the redirecting means comprise optical coupling means for redirecting light signals to an optical fibre other than said optical fibre for transmission to the optical detector



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arrangement.

5. A sensor array as claimed in any preceding claim wherein a reference cable is positioned in close proximity to the sensor array to permit common-mode noise to be cancelled.

6. A sensor array as claimed in any preceding claim wherein the detection means comprises means for analysing the returned signal and means for comparing it with stored data in order to classify the detection.

7. A sensor array as claimed in any preceding claim wherein the light source comprises a laser source, and an optical switch for directing light from the laser source along two paths one of which has an optical delay therein and one of which has an optical phase shifter therein, such that in use the light source transmits to the fibre two time displaced pulses at different frequencies.

8. A sensor array as claimed in any one of claims 1 to 7, in which the light source comprises a Bragg cell for combining and launching light signals of different wavelengths into the single optical fibre, the Bragg cell being arranged to be pulsed sequentially at different

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predetermined frequencies in order to produce like deflections of incoming light signals at different wavelengths.

9. A sensor array as claimed in any preceding claim for monitoring vehicles on a highway.

10. A sensor array as claimed in any one of claims 1 to 8 claim for detecting an intruder.

11. A sensor array as claimed in any one of claims 1 to 8 for detecting displacement of machinery.

12. A sensor array as claimed in any preceding claim comprising means for generating a plurality of light sources of different frequencies, and a plurality of sets of redirecting means, wherein different set of redirecting means are associated with different light sources.

13. An optical fibre sensor array substantially as hereinbefore described with reference to any one of the accompanying drawings.

Examiner's report to the Comptroller under  
Section 17 (The Search Report)

Application number

9127358.1

Relevant Technical fields

(i) UK CI (Edition K ) H4B: BK12;BK12M;BK12S;BK20;BK20S;  
BK20S1;BK20S2;BK20T;BK20T1;BK20T2;  
G1A: BG;CEX;MQX; H4D;DLF  
(ii) Int CL (Edition 5 ) G01N, G01B, G01L, G01P, G08B,  
H04B, G01M

Search Examiner

A C STRAYTON

Databases (see over)

(i) UK Patent Office

(ii)

Date of Search

17 JUNE 1992

Documents considered relevant following a search in respect of claims

ALL

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
X	GB 2250593 A - entire document	1-13
X	GB 2214636 A - entire document	1-13
X	GB 2209212 A - entire document	1-13
X	GB 2202046 A - entire document	1-13
X	GB 2190262 A - entire document	1-13
X	GB 2126820 A - entire document	1-13

Category	Identity of document and relevant passages	Relevant to claim(s)

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**P:** Document published on or after the declared priority date but before the filing date of the present application.

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**Databases:** The UK Patent Office database comprises classified collections of GB, EP, WO and US patent specifications as outlined periodically in the Official Journal (Patents). The on-line databases considered for search are also listed periodically in the Official Journal (Patents).

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# (12) UK Patent Application (19) GB (11) 2 264 018 (13) A

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 (52) UK CL (Edition L)  
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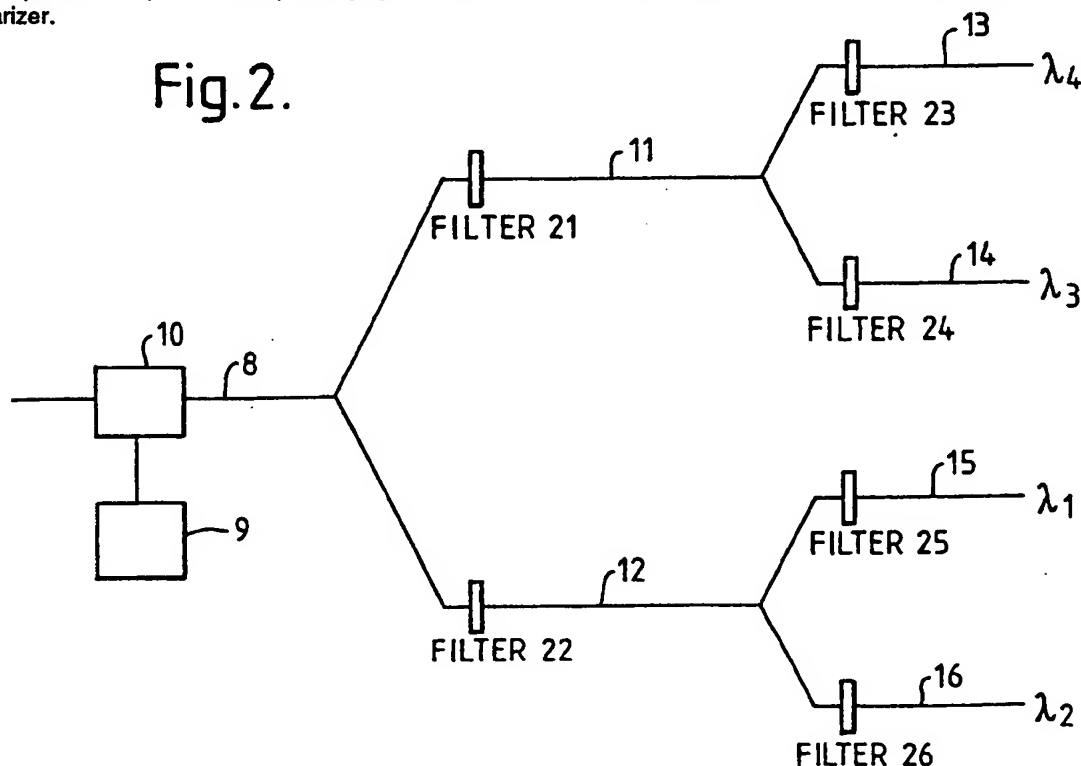
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Multiplexed and distributed optical fibre sensors sys

 (58) Field of search  
UK CL (Edition L) G1A ABG ACD ACE, H4D DLF  
INT CL<sup>5</sup> G01M

## (54) Optical signal transmission network

(57) A means for simplifying fault location in an optical signal transmission network in which a main optical fibre 8 is divided into a plurality of branch circuits 11 to 16, comprises optical time domain reflectometry (OTDR) equipment 10 for transmitting an output signal along the main fibre, and for each branch circuit means 21 to 26 for causing the signal returned to the OTDR equipment from the branch to be modified in a manner unique to that branch. The branch circuit means 21 to 26 may each comprise a filter passing light at one or more distinctive frequency bands, a frequency modulator, or a polarizer.

Fig.2.



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Fig.1.

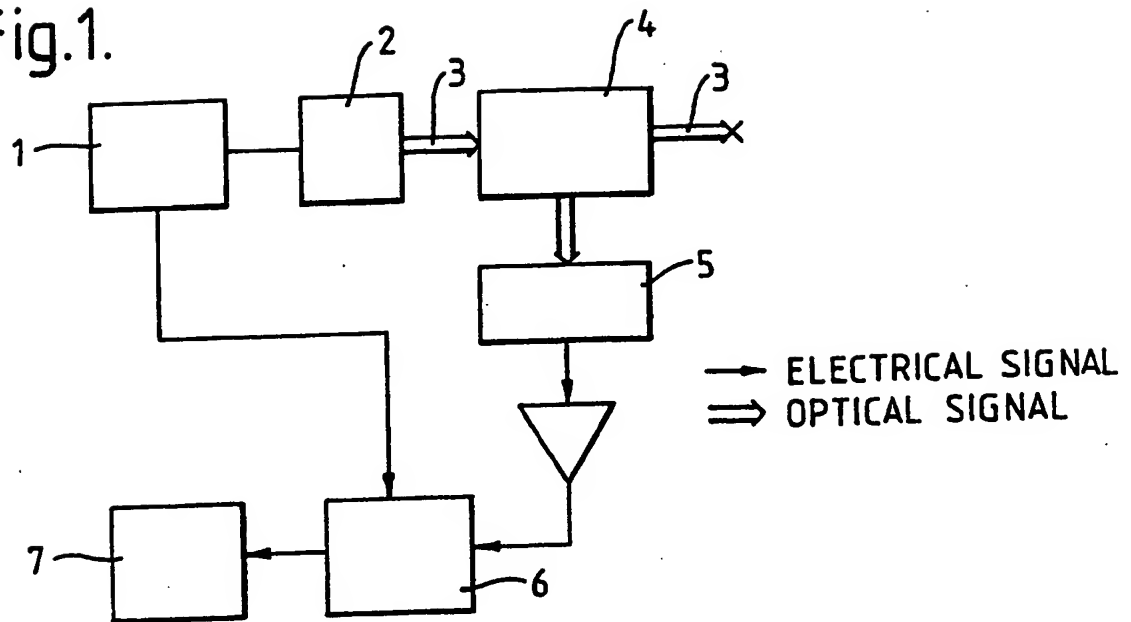


Fig.2.

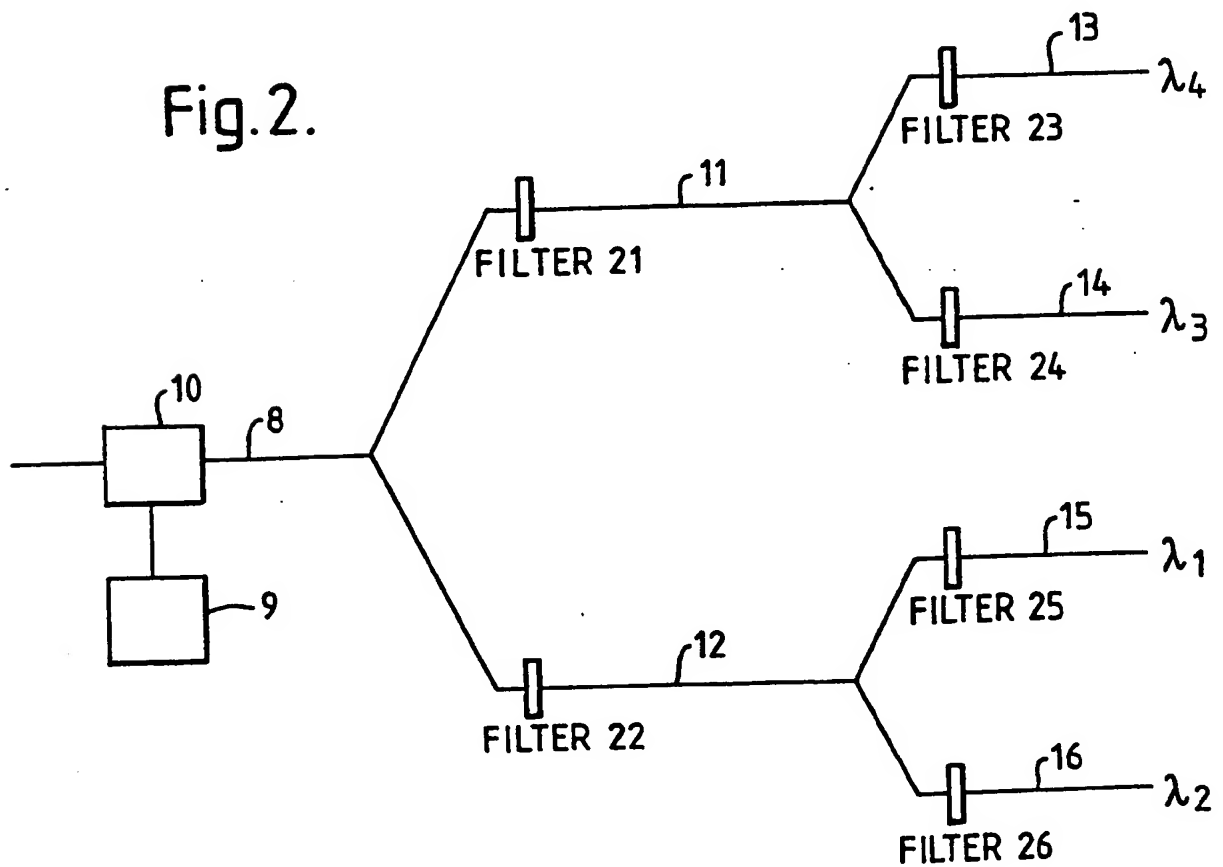


Fig. 3.

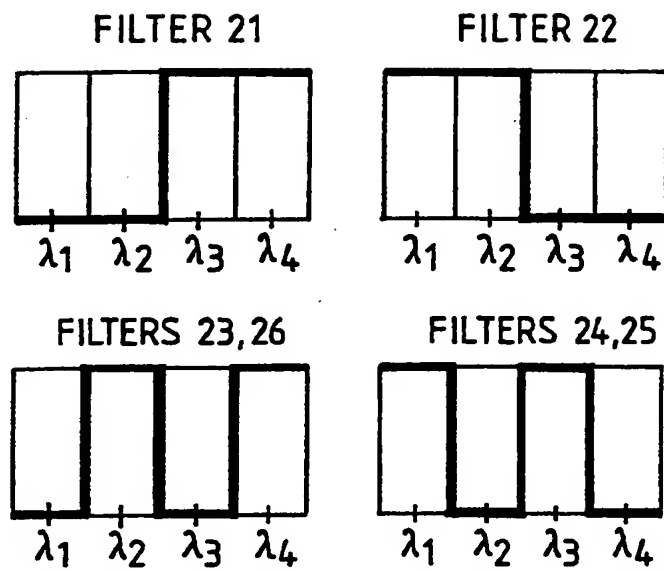
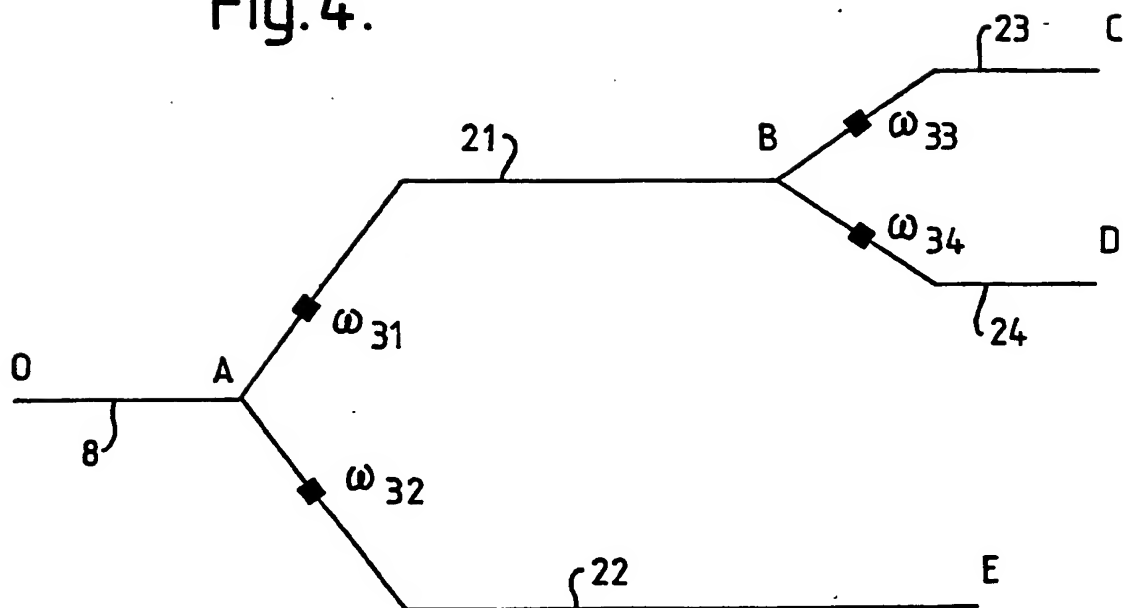


Fig. 4.



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OPTICAL SIGNAL TRANSMISSION NETWORK

This invention relates to optical signal transmission networks, as may be used, for example, in optical fibre telecommunications, and relates, in particular, to a fault location and diagnostic systems for use with such networks.

Over the past decade, optical time domain reflectometry, hereinafter referred to as OTDR, has become an established tool for the location and evaluation of the features on an optical fibre route. For example, OTDR techniques are now commonly used to determine both the position and loss of splices and connectors and the position of line breaks as well as providing a means for making single-ended, real-time system loss measurements.

In use of an optical time domain reflectometer a short pulse of light is launched into an optical fibre under test and the backscattered signal is monitored as a function of the time of flight (or equivalently distance) along the fibre. The magnitude of the backscattered signal depends on the Rayleigh scattering, attenuation, inhomogeneities, splices, components and the optical power level in the fibre. Features in the trace of backscatter versus time may then be correlated with the presence of discontinuities and disruptions in the fibre route.

Whilst OTDR techniques are extremely valuable as a



diagnostic tool for the location of faults in simple point to point links there is now an increasing trend towards more complex passive optical networks.

In such networks a number of branch circuits may emanate from a single optical fibre connected, for example to a telephone exchange, and the branch circuits may be further divided into further branch circuits. Such an arrangement can provide a significant cost reduction by utilising the available bandwidth to share said single exchange fibre amongst a number of customers, thereby reducing the level of exchange equipment and fibre installation costs borne by each customer.

It will, however, be apparent that when a signal from OTDR equipment is transmitted along said single fibre, and thence to the branch circuits, the signal which is returned at any instant, following the transmission of an output signal from the OTDR equipment, will be made up of light backscattered from many points in the network at the same distance from the equipment. This makes the location of a fault in the network difficult and time-consuming.

An object of the invention is to provide a means of simplifying such fault location.

According, therefore, to the invention, in an optical signal transmission network comprising a main optical fibre having a plurality of branch circuits, and associated with OTDR equipment connected so as to transmit an output signal through said main fibre and said branch circuits, each said branch circuit incorporates, means for causing the signal returned to the OTDR equipment from said branch to be modified in a manner unique to that branch, and the OTDR equipment has means for distinguishing the signals returned from the individual branch circuits.

In one arrangement in accordance with the invention, the OTDR is capable of being tuned to provide signals in a selected wavelength band, and each branch circuit incorporates a filter capable of passing traffic wavelengths, and one or more respective pass wavelengths in the OTDR band, without significant loss, but of

attenuating all other wavelengths in the band, the filters being so related that a signal returned to the OTDR equipment from any branch of the network has a wavelength unique to that branch. Accordingly any branch circuit having a fault can be unambiguously identified, and measurement of fault conditions can be carried out as in a point to point, rather than a point to multipoint system.

In an alternative arrangement each branch circuit incorporates means for modulating the output signal from the OTDR equipment at a unique frequency and the OTDR incorporates detector means capable of being tuned to respond to a selected one of individual frequencies of the various branch circuits.

Instead of straightforward loss modulation of the OTDR output signal, each of the individual branch circuits may incorporate, instead, means for modulating the state of polarisation of the output light signal from the OTDR equipment in a unique manner, the OTDR incorporating means for detecting the state of polarisation of the returned signals. Decoding of the returned signal may be achieved by splitting it into two polarised components, the intensity of which will have components at the modulation frequency. Unambiguous measurements of the various route segments may then be made as with the loss modulation technique.

The filters or modulating means, as the case may be, are preferably disposed adjacent the beginning of the respective branches.

The invention will be further explained by way of example with reference to Figures 1 to 4 of the accompanying drawings, in which:

Figure 1 represents in diagrammatic form a typical OTDR system,

Figure 2 represents part of an optical fibre telecommunication network employing one embodiment of the invention,

Figure 3 illustrates the manner of operation of this embodiment of the invention, and

Figure 4 represents part of an optical fibre telecommunication network employing an alternative embodiment of the invention.

Referring first to Figure 1, the OTDR equipment illustrated incorporates an electrical pulse generator 1, the output of which is fed to means 2 for producing a light signal in a selected waveband, and this is fed, in turn, into an optical fibre 3.

When a signal is generated by the OTDR equipment, a signal will be returned along the fibre 3 made up of light backscattered from splices, disconformities and possible faults in the fibre, the returned signal being fed via a directional coupler or beam splitter 4 to a convertor 5 and detector 6 responsive to the returned signal, and display means for indicating the signal value at selected instants following the transmission of the output signal, i.e. after selected round trip delay times, and this accordingly enables the location of any fault in the fibre to be readily determined.

Such an arrangement operates quite satisfactorily where there is only a single output fibre. However where the fibre 3 has connected to it a plurality of branch circuits, as, for example in the case of an optical telecommunication system, the returning signal at any instant will be made up of light backscattered from many individual points at the same distance from the OTDR equipment, making the extraction of useful information from the equipment extremely complex.

Figure 2 illustrates how the invention avoids this difficulty, and represents, in simplified form, part of an optical fibre telecommunication network comprising a main fibre 8 connected to a telephone exchange (not shown) and feeding two branch circuits 11, 12, each of these feeding, in turn, two further branch circuits 13, 14 and 15, 16 respectively.

OTDR equipment, shown diagrammatically at 9 feeds output signals into the fibre 8 through suitable coupling means 10, the signals being transmitted from the fibre 8 into the various branch

circuits. In accordance with the invention each branch circuit is provided, adjacent the respective branch point, with a dielectric filter 21, 22, 23, 24. The filters are such that they do not introduce any significant loss at traffic wavelengths (for example 1200 to 1570 nm) or at the designated OTDR pass wavelength, but are such that signals returned to the OTDR equipment from any branch of the network have a wavelength unique to that branch. Accordingly each possible route is assigned a unique OTDR wavelength, and by tuning the OTDR source wavelength across the allocated OTDR band, each individual route will be selected in turn.

Characterisation of the selected route may then proceed as if it is a simple point to point link.

Figure 3 illustrates a manner in which this may be achieved in the simple branch circuit shown in Figure 2. Thus filter 21 heavily attenuates or reflects wavelengths  $\lambda_1$  and  $\lambda_2$ , while passing wavelengths  $\lambda_3$  and  $\lambda_4$ . Filter 22 heavily attenuates or reflects wavelengths  $\lambda_3$  and  $\lambda_4$  while passing wavelengths  $\lambda_1$  and  $\lambda_2$ . Filters 23 and 26 heavily attenuate or reflect wavelengths  $\lambda_1$  and  $\lambda_3$  and pass wavelengths  $\lambda_2$  and  $\lambda_4$  and filters 24 and 25 heavily attenuate or reflect wavelengths  $\lambda_2$  and  $\lambda_4$  and pass wavelengths  $\lambda_1$  and  $\lambda_3$ .

It will therefore be seen that wavelength  $\lambda_4$  is unique to branch 13,  $\lambda_3$  to branch 14,  $\lambda_1$  to branch 15 and  $\lambda_2$  to branch 16.

Figure 4 illustrates part of an optical fibre telecommunication network comprising a main fibre 8, first branch circuits 21, 22 and further branch circuits 23, 24. In this case each of the branch circuits 21 to 24 incorporates, adjacent the branch point, a modulator 31 to 34 respectively. OTDR equipment feeds output signals into the fibre 8 through suitable coupling means (not shown), and the modulators in the various branch circuits are arranged to modulate the OTDR signals at unique wavelengths.

The length OA is single pathed and hence may be characterised by standard 'DC' OTDR measurements. Lengths ABC and ABD return OTDR signals modulated at frequency 31, and will

therefore have a non-zero component at this frequency, whilst route AE, which is modulated at  $\omega_{32}$ , has no component at 31. Thus length AB has been uniquely determined. Similarly selecting frequency  $\omega_{33}$  or  $\omega_{34}$  allows measurement of BC or BD respectively.

Many mechanisms for such loss modulation may be envisaged, but a low cost, clip-on modulator would be ideal. This restricts the modulation scheme to one in which the fibre is physically perturbed. If primary coated fibre is accessible, then microbending may be conveniently used to induce loss, whereas jacketed fibre could more easily be modulated by inducing periodic bulk bend loss. Acousto-optic or other forms of modulators might also be used for some applications. The depth of the loss modulation will, however, be limited by the need to maintain a minimum required error performance for the system.

In a modification of the embodiment illustrated in Figure 4, the modulators 31 to 34 may be replaced by modulators which modulate the polarisation of light under examination. By this means it is possible to determine the returned signal without disrupting traffic signals to any significant extent. Decoding of the returned signal can be achieved by splitting it into two orthogonally polarised components, the intensity of which will have components at the modulation frequency. Unambiguous measurements of the various route segments may then be made as with the loss modulation technique described above.

It will be appreciated that although the invention has been explained with reference to simple networks, it can readily be applied to more complicated networks, by the use of suitable filters or modulators as the case may be. Moreover although it is primarily concerned with the location of faults in optical fibre telecommunication systems it may also be used to advantage in other systems employing multibranch optical fibre networks.

CLAIMS

1. An optical signal transmission network comprising a main optical fibre having a plurality of branch circuits, and associated with OTDR equipment connected so as to transmit an output signal through said main fibre and said branch circuits, wherein each said branch circuit incorporates, means for causing the signal returned to the OTDR equipment from said branch to be modified in a manner unique to that branch, and the OTDR equipment has means for distinguishing the signals returned from the individual branch circuits.
2. An optical signal transmission network according to Claim 1 wherein the OTDR is capable of being tuned to provide signals in a selected wavelength band, and each branch circuit incorporates a filter capable of passing traffic wavelengths, and one or more respective pass wavelengths in the OTDR band, without significant loss, but of attenuating all other wavelengths in the band, the filters being so related that a signal returned to the OTDR equipment from any branch of the network has a wavelength unique to that branch.
3. An optical signal transmission network according to Claim 1 wherein each branch circuit incorporates means for modulating the output signal from the OTDR equipment at a unique frequency and the OTDR incorporates detector means capable of being tuned to respond to a selected one of individual frequencies of the various branch circuits.
4. An optical signal transmission network according to Claim 1 wherein each of the individual branch circuits incorporates means for modulating the state of polarisation of the output light signal from the OTDR equipmnt in a unique manner and the OTDR incorporates means for detecting the state of polarisation of the returned signals.
5. An optical signal transmission network according to Claim 4 wherein the detecting means comprises means for splitting the returned signal into two polarised components.
6. An optical signal transmission network according to any preceding claim wherein the filters or modulating means, as the case

be, are disposed adjacent the beginning of the respective branch points.

7. An optical signal transmission network substantially as hereinbefore described by way of example with reference to Figures 2 and 3 or Figure 4 of the accompanying drawings.

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**Patents Act 1977**

**Examiner's report to the Comptroller under  
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**Relevant Technical fields**

(i) UK Cl (Edition L ) H4D (DLF) G1A (ACE, ABG, ACD)

(ii) Int Cl (Edition 5 ) G01M

**Databases (see over)**

(i) UK Patent Office

(ii)

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**Documents considered relevant following a search in respect of claims**

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
X	GB 2190264 A (FOUCALT) Whole document	1
AP	WO 92/09873 A1 (FURUKAWA ELECTRIC) Whole document	1, 3
X	WO 91/15744 A1 (BRITISH TELECOM) eg. page 1 line 20 - page 2 line 9 page 3 lines 6-18	1, 3, 6
X	WO 90/06498 A1 (BRITISH TELECOM) eg. page 1 line 24 - page 2 line 21 page 6 line 26 - page 7 line 10	1, 3
X	J Phys E: Sci Instrum 20 (1987) pages 954-967 J P Dakin: Multiplexed and distributed optical fibre sensor systems particularly Figures 2(b) and 82(3).	1, 3



Category	Identity of document and relevant passages	Relevant to claim(s)

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